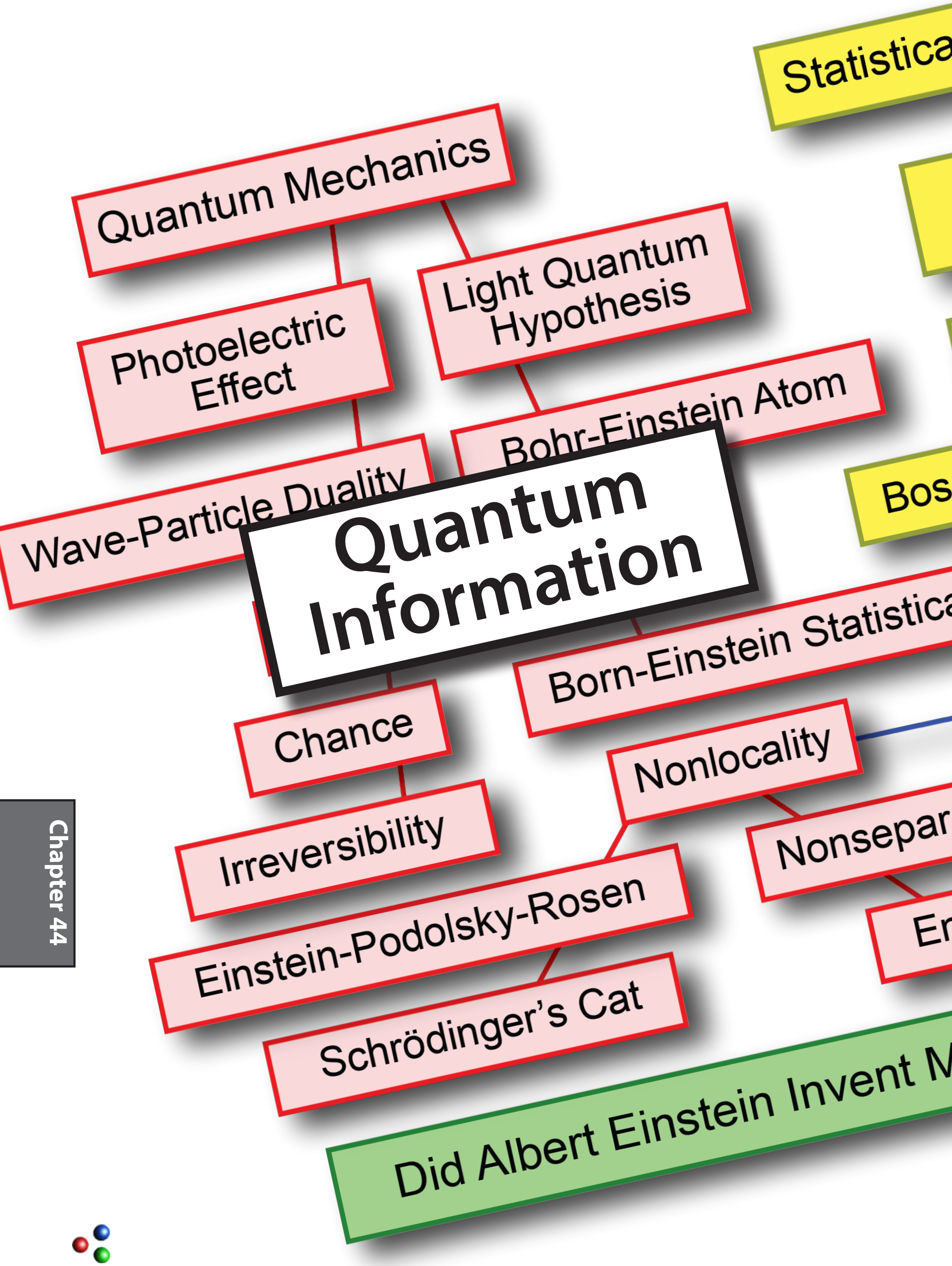
Quantum Information



Quantum Information

Quantum information, quantum computing, quantum encryption with key distribution, and quantum teleportation, are all described as using *entanglement as a resource*.

So the key question for Einstein's "objective reality" view is whether its "objective" form of entanglement is identical to the concept of quantum entanglement, so as to be useful.

In Einstein's first description of a two-particle system that might be *nonseparable* (he of course mistakenly hoped they could be separable), it was the linear momentum that exhibited "action-at-a-distance." We now understand linear momentum as a "hidden constant" of the motion, giving us "knowledge-at-a-distance."

In our extension of Einstein's "objective reality," all other properties of the two-particle entangled system (angular momentum, spin, polarization) travel along with the particles, conserved as "hidden constants," from their initial entanglement in the center of their "special frame."

The angular momentum, spin, and polarization vectors have not been "measured" at their entanglement. Entanglement is not a "state preparation." Angular spin components are undefined.

It is thus the projections of some properties by "Alice" in specific directions that are instantly correlated with Bob's particle at all spacelike separations.

We start with the two-particle quantum wave function, which in standard quantum mechanics is described as a *superposition* of two-particle states,

$$\psi = | + - > - | - + >.$$

Paul Dirac tells us that superposition is just a "manner of speaking" and that an individual system is in just one of the superposed states, although there is no way to know which, so say it is

$$\psi = | + - >.$$

Upon disentanglement by any external interaction, say by a measurement/collapse of the two-particle wave function, this becomes the product of two single-particle wave functions,

$$\psi = | + > | - >.$$

We can visualize the | + > state as keeping the + spin or polarization of the *directionless* spin, but still without that state having a specific spatial component, e.g., z+. It is when a measurement is made that two things happen. 1) the wave function is factorized. 2) The single-particle wave functions both acquire a spatial component direction. One will be a projection of | + >, the other of | - >. These two must be in opposite spatial directions in order to maintain the conservation of total spin zero!

These will be acquired *simultaneously*, in apparent violation of special relativity. But nothing is traveling between them. Whoever measures first, Alice or Bob, breaks the symmetry of the directionless spins in the two-particle wave function and forces the two spins into opposite spatial directions, say z+ and z-.

Subsequent examination of the pairs of measurements by Alice and Bob in the same direction will reveal their perfect correlations. There is no way this can be used for faster-than-light communications.

Notice that if Bob makes a measurement after Alice, it has no effect on Alice's particle. They have been decohered, disentangled, and finally separated. For example, if Bob measures at a different angle α, he will get weaker correlations proportional to $(\cos \alpha)^2$, as predicted by quantum mechanics.[1]

John Bell's claim that "hidden variables" would produce straight-line correlations has no physical foundation whatever. When Bell says that "the Einstein program fails," it is Bell's physically absurd straight line correlation, with "kinks," that fails. See chapter 32.

Objectively real "hidden constants" are not mysteriously transmitted instantaneously, which is impossible. They are carried along at the particles' speed as "constants of the motion." The spatial components in a particular direction are not carried along, they are *created* by the measurement, with the direction a "free choice" of the experimenter.

The most obvious "hidden constant" is the particle momentum, whose conservation was used in the 1935 EPR paper.

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[1] See Dirac's discussion of polarizers in chapter 19.

Entangled Qubits

In order to decide if this entanglement is good enough for quantum computing, we need to know how the qubits in a particular quantum computer get entangled. And then we need to understand the type of directional *measurement* that *creates* the perfectly correlated (or anti-correlated) states at any distance.

There are at least a dozen physical realizations of a quantum computer. They all involve a number of entangled qubits, arranged in a sequence. They are typically very close together, for example arranged in a vertical (z) column in an ion trap that constrains their x and y positions. An array of ion traps can be arranged in a quantum charge-coupled device (a QCCD chip). A large array has areas for memory storage and interaction areas for implementing algorithmic computations.

Qubits are initialized, stored as computer memory, then manipulated to communicate (teleport) data from qubit to qubit.

The qubits are initialized by a laser that optically "pumps" the ion from its ground state, either into a hyperfine state (the electron spin flips to be parallel with the nuclear spin), or the electron is pumped up into an "excited" but "metastable" state (one of the atom's optical energy levels that cannot drop back to the ground state with a single-photon quantum jump).

Pairs of qubits can now be entangled by the application of quantum logic gates like the "controlled not" (C-NOT). Qubits can then be teleported between different ion traps in the array. They can also be converted to light and sent through photonic channels, locally or out over fiber optic cables or free space transmission to satellites and beyond.

"Objectively real" qubits in the form of "hidden constants" have values that were determined at the time of entanglement. But they are fully correlated and perfectly random bit sequences.

The fully correlated "Bell states" or "EPR pairs" that appear at an arbitrary angle decided by Alice's "free choice" may also have been hidden in directionless spin states. Whether they are adequate for quantum information systems remains to be decided.